Project Summary for NEHRP FY 2001:

Preliminary Paleoseismic Results on the Owens Valley Fault Zone and Latest Quaternary Stratigraphy in Owens Valley near Lone Pine, eastern California

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Project Introduction and Purpose

On March 26, 1872, the Owens Valley fault zone (OVFZ) in east-central California hosted the third largest magnitude (Mw 7 1/2 to 7 3/4) historical earthquake in the western United States. The ground ruptured for 100±10 kilometers (km), from the southern shores of Owens Lake to just north of Big Pine (Figure 1), having 6.0±2.0 meters (m) of right-lateral displacement with 1.0±0.5 m of normal slip (Beanland and Clark, 1994). The timing of paleoearthquakes and a long-term (mid to late Pleistocene) slip rate are poorly known for the OVFZ, which is one of a broad group of mainly right-lateral and normal faults within the Eastern California Shear Zone (ECSZ). The ECSZ accommodates as much as one-fourth of relative dextral slip motion between the Pacific and North American plates inboard of the San Andreas plate boundary (Sauber and others, 1994). The OVFZ seismic history and slip rate have important implications for local and regional hazard assessments (Burke and others, 2001) as well as geodetic models of current deformation in the western United States (Sauber and others, 1994).

This Project Summary for the National Earthquake Hazards Reduction Program (NEHRP) describes preliminary results of our ongoing research near Lone Pine in light of previous and recently published investigations regarding the OVFZ paleoearthquake history and fluctuations of pluvial Owens Lake. The original project proposal is by Burke and others (2000). Preliminary results of this project's research were presented in December 2000 at the American Geophysical Union Fall Meeting in San Francisco, California (Bacon and Burke, 2000).

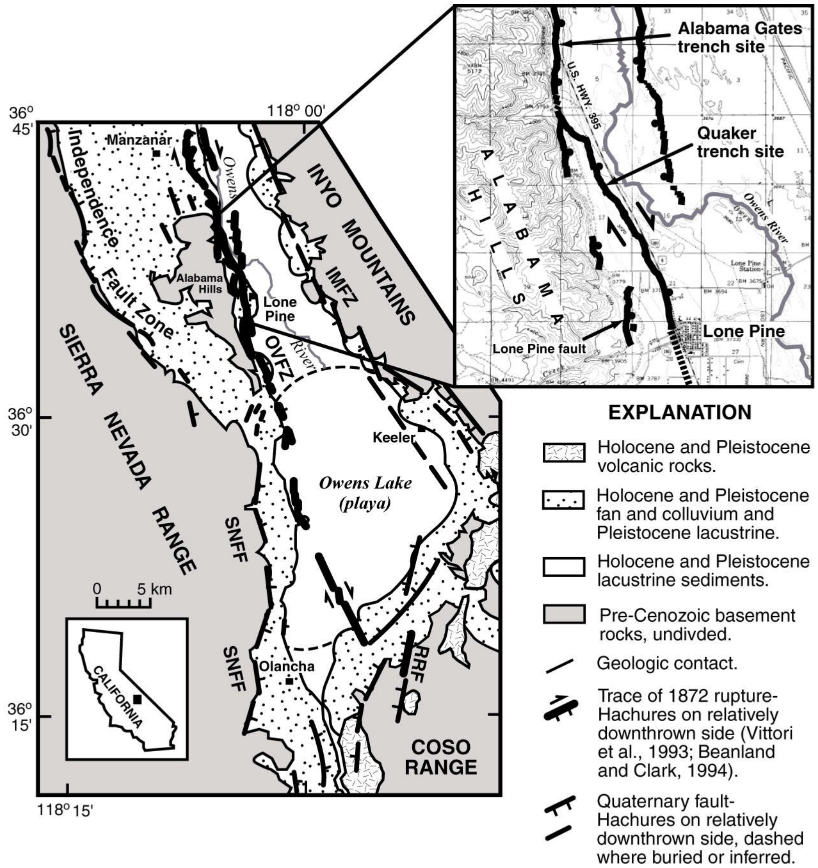

Figure 1. Generalized fault and geology map of southern Owens Valley, California. Principal fault zones and the southern segments of the 1872 Owens Valley fault rupture are modified from Hollet and others (1991) and Beanland and Clark (1994). OVFZ, Owens Valley fault zone, from Bryant (1988), Vittori and others (1993), Beanland and Clark (1994); IMFZ, Inyo Mountain fault zone from Jennings (1994); RRF, Red Ridge fault from Vittori and others (1993); SNFF, Sierra Nevada Frontal-faults from Carver (1970), Vittori and others (1993), Beanland and Clark (1994); and Independence fault zone from Jennings (1994). Nested map shows the location of the trench sites and the OVFZ relative to the town of Lone Pine (base map: USGS 15' Lone Pine quadrangle).

Non-Technical Project Summary

This project is progressing on six main tasks. We have been and are currently: (1) correlating the stratigraphy between the trench sites and nearby natural exposures in order to develop a stratigraphic facies model of lacustrine fluctuations as a function of elevation; (2) awaiting lab results of tephra and 14C samples, submitting more samples, and continue to search for and collect more samples in order to date the latest Quaternary stratigraphic section in the study area; (3) continuing to map the surface geology of the trench sites in better detail, incorporating suggestions of the NEHRP 2002 review panel; (4) comparing the trench stratigraphy and structures to geomorphic analyses of scarp and shoreline profiles; (5) continuing to study climate change analyses primarily from Owens Lake core data in order to better constrain the timing of both lake level fluctuations and paleoearthquakes in the Owens Valley; and (6) in the middle to final stages of writing the project results for a publication submission as a peer review journal article (GSA Bulletin) and as a Master's thesis requirement (S. Bacon, Humboldt State University).

Our Ongoing Research near Lone Pine

Humboldt State University students and staff (lead by S. Bacon), and USGS personnel and volunteers have been working for the past 5 years with local residents, Los Angeles Department of Water and Power staff, and California Department of Transportation (CalTrans) personnel (during construction of parts of Highway 395 near Lone Pine) to recognize and study suitable paleoseismic sites along the OVFZ. To date, we have mapped the stratigraphy and structure in 7 fault trenches, 3 deep strata pits, 29 natural and human-dug exposures, in numerous hand-augered holes on, or in the vicinity of, the OVFZ, and ca. 1.5 km of Owens River bluff exposure near Lone Pine, California (Figure 2).

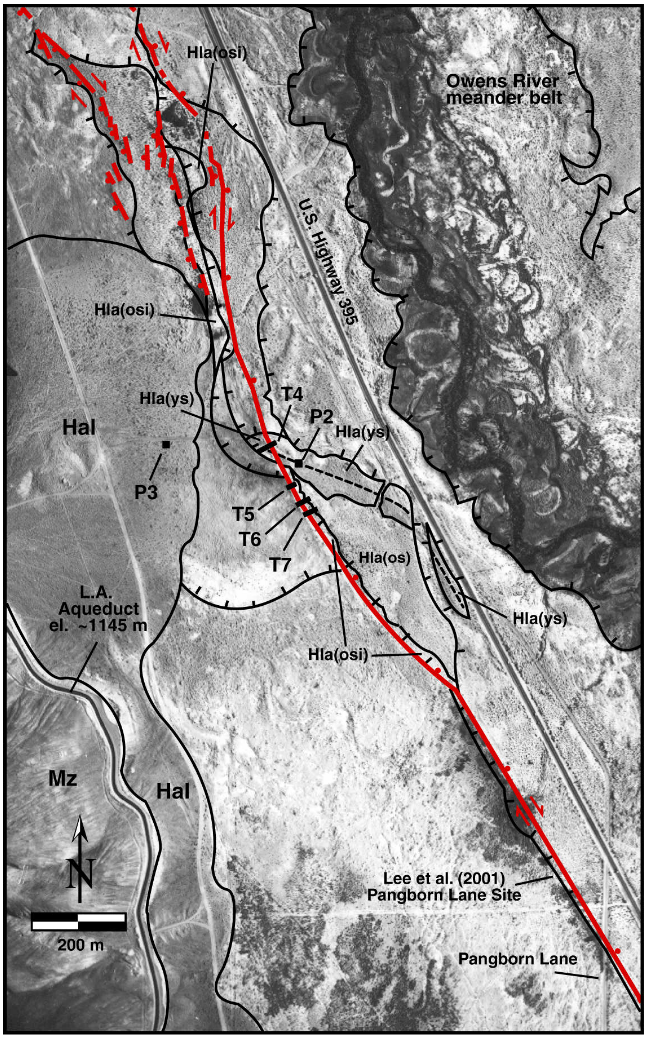

Figure 2. Low-sun-angle aerial photograph of the Quaker Trench site north of Pangborn Lane. Fault trenches (T4 through T7) and strata pits (P2 and P3) are shown relative to the 1872 Owens Valley fault trace (in red), the Alabama Hills (Mz), Holocene alluvium derived from the Alabama Hills (Hal), and prominent tread and risers (hatching). Aerial photo base is from the 1968 D.B. Slemmons Owens Valley archive at the MacKay School of Mines, Reno, Nevada.

In all of the exposures, which we match to numerous topographic profiles of the scarps and shorelines, structural evidence for only two earthquakes is certain, the historic 1872 and an older paleoearthquake, likely the penultimate event. The geologic relations are similar at nearby trench sites. The vertical separation and deformation from the paleoearthquake appears similar to that of the 1872 event. The age of the older event is likely middle to early Holocene. These results are preliminary, pending dating analyses and more trench work, as summarized most recently by Bacon and Burke (2000) and our unpublished FY2002 NEHRP Continuation Proposal (Burke and others, 2001). Next, we present the bases for some of our initial stratigraphic and structural interpretations from the trench data and ongoing mapping in the area.

Alabama Gates Paleoseismic Site

In March of 1999, 3 trenches and 1 deep strata pit were excavated at the Alabama Gates trench site, equivalent to Site 15 of Beanland and Clark (1994). These exposed mainly hanging-wall deformation that we interpret was likely a result of two earthquakes including 1872 since 10.19±0.07 thousand of years before present (ka) (date from Table 3; Beanland and Clark, 1994). The principal fault zone is exposed in trench T2 (Figure 3) and displays the most apparent vertical separation of all three trenches, 1.0±0.2 m attributed to the 1872 event. The sediments are lacustrine; clayey silts are overlain by beach berm sands, near-shore silty sands, and back berm/marsh sediments (black unit in the figure). Beach berm sediments are deposited on an abrasion platform.

We interpret the clayey silt rip-up clasts, within the sands and back berm/marsh, sediments are likely related to erosion into a pre-existing fault scarp composed of a deeper lacustrine stratigraphic section. The silty sand with trace angular pebble units that overly the back berm/marsh sediments may be related to fault- or lacustrine-related colluvial wedges. Lateral slip is obvious from the unit thickness and lithologic changes across the faults.

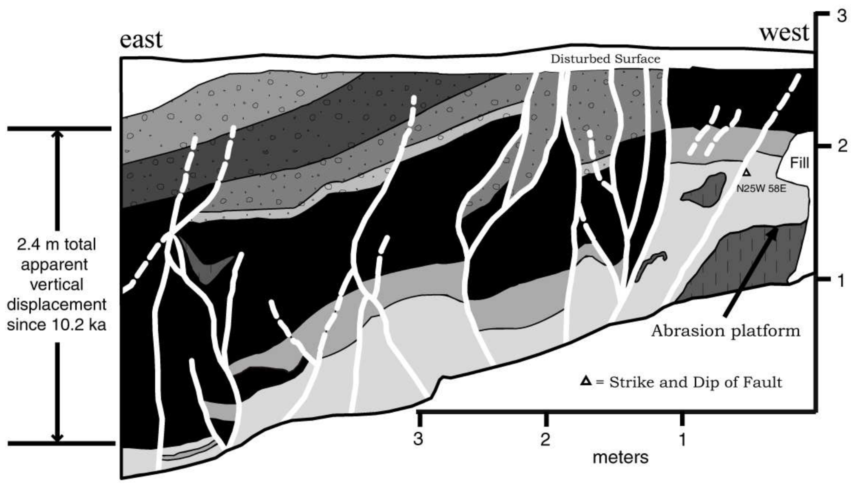

Figure 3. Log of south wall of Trench T2, Alabama Gates. See text for explanation.

Trench T1 (Figure 4) is located ca. 15 m north of T2 and exhibits similar relations. The stratigraphy consists of beach berm sands, near-shore silty sands, and back berm/marsh sediments (black unit in the figure). Silty sands with trace angular pebbles overly the back berm/marsh sediments and upward termination of fault strands. We speculate that the apparent upward termination of west-dipping faults may be associated with a paleoearthquake, most likely the penultimate event at this site. A separate set of west-dipping fault strands and a fissure fill is attributed to the 1872 earthquake. Trench T1 also contains Stage I+ carbonate filament development that we interpret to represent a weak paleosol or buried surface. The net apparent vertical offset across all faults within T1 and T2 is 2.4±0.2 m. This throw in approximately 10 k.y. provides an apparent vertical two-event slip rate of 0.24±0.02 m/ky. This rate is similar to the long-term (middle Pleistocene) vertical slip rate determined by Martel and others (1987) and Zehfuss and others (2001) on the Fish Springs fault, a splay of the OVFZ south of Big Pine, located 40 km north of our trench sites.

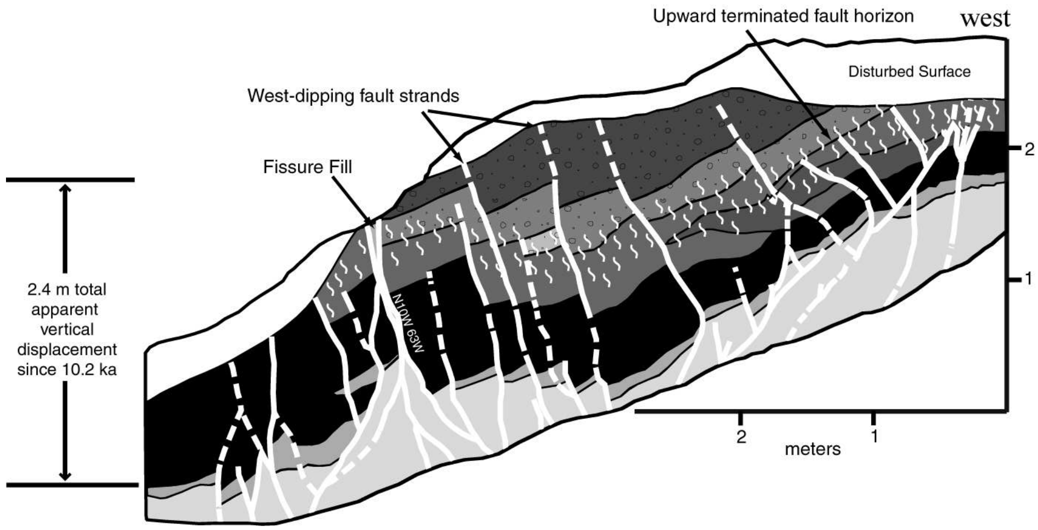

Figure 4. Log of south wall of Trench T1, Alabama Gates. See text for explanation.

Quaker Paleoseismic Site

In March of 2001, NEHRP funding gave us the opportunity to open 4 more trenches and 2 deep strata pits, at what we call the Quaker site, equivalent to Site 12 of Beanland and Clark (1994). The Quaker site is approx. 3.0 km south of the Alabama Gates site, 4.0 km north of Lone Pine, and several 100 meters west of old Highway 395 (Figures 1 and 2). The four Quaker trenches cross the OVFZ at a similar elevation as the three Alabama Gates trenches, approximately 1125 m. The stratigraphic section is remarkably similar to Alabama Gates yet Quaker also had sections somewhat lower and more complete. All three trenches: T5, T6, and T7 (T5 is Figure 5; T6-T7, not shown), expose massive lacustrine beach, lacustrine colluvial and deep water facies in the footwall, faulted against likely fluvio-deltaic to near-shore lacustrine packages of well bedded to massive, fine to pebbly, silt-rich and/or (Owens River) lithic-rich sands and gravels beneath fine to medium aeolian dune sands in the hangingwall. What we refer to as "Owens River lithics" have various mixtures of scoria, pumice, and tuff seen locally and commonly in fluvial deposits in the Owens River meander belt.

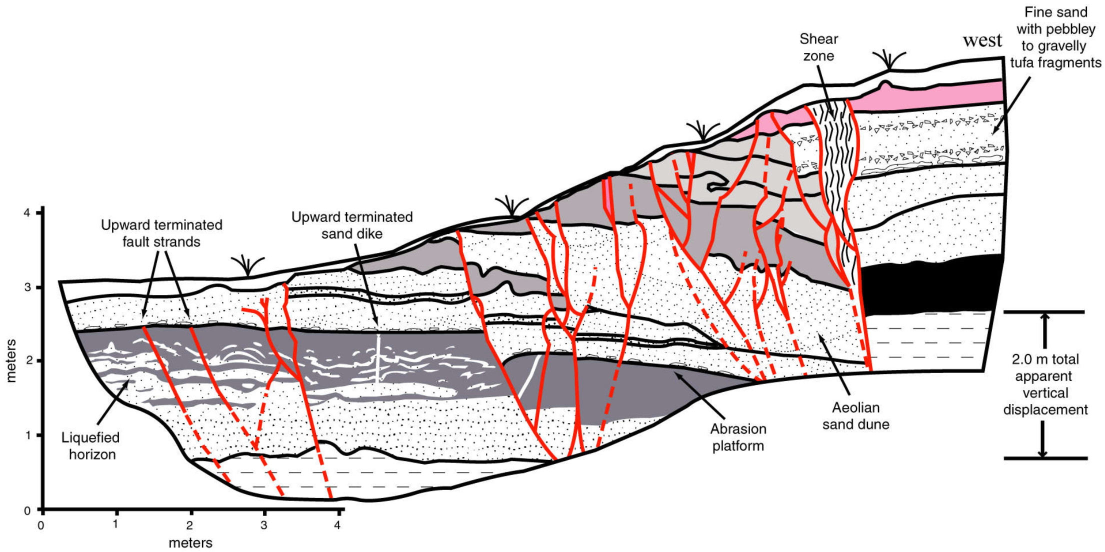

Figure 5. Log of south wall of Trench T5, Quaker Site. See text for explanation.

Trench T5 is the best example of the stratigraphy and structure near the Quaker site (Figure 5). The section consists of beach berm sands, near-shore silty sands (gray units), an interbedded aeolian sand dune, and fine sand with fragmented pebbly to gravelly tufa that overly organic rich back berm clayey silts (black unit in the figure), and clayey silts (dashed unit). Two principal zones of faulting strike parallel to the scarp and are separated by approx. 3-10 m. Lateral slip is clear on both zones. Trench T5 shows upward termination of fault strands and sand dikes along with a prominent liquefied horizon stratigraphically below an abrasion platform that we interpret to be related to basal erosion from a middle to early Holocene lake transgression. We interpret with high confidence that these relations are associated with a paleoearthquake, most likely the penultimate event at this site.

A separate set of west-dipping to near vertical fault strands and fissure fills are attributed to the 1872 event. Only 1872 faulting deforms the two fining upward packages of lacustrine sediment above the abrasion platform. The total apparent vertical deformation attributed to the 1872 event here is 0.7±0.2 m, measured using 6 piercing points across all faults above the abrasion platform. The total apparent vertical deformation from the 1872 and penultimate events is 2.0±0.2 m, measured from the elevation difference using the deepest silty clay unit below the abrasion platform and the same unit on the other (west) side of the fault zone (Figure 5).

Geomorphology and Pluvial Owens Lake Levels

One of the principal findings we rely on is that Owens Lake sediment cores studied by Benson and others (1996; 1997), Smith and others (1997), Lund and others (1998), Smoot (1998), Forester (2000), and Li and others (2000), in addition to stratigraphic and geomorphic data presented by Orme and Orme (1993; 2000), Stone and others (2000), and Bacon and Burke (2000), indicate that pluvial Owens Lake water levels fluctuated throughout the Holocene, mostly within the basin at elevations below the overflow sill elevation of 1145 m. Fault scarps at and near our trenches north of Lone Pine (Figures 1 and 2) are at elevations of ca. 1125 m, which is approximately 20 m below the sill elevation. Thus the OVFZ scarps at lower elevations were modified by fluctuating shorelines and associated fluvial-lacustrine burial or erosion in middle Holocene time, in places enhancing, obscuring, or removing evidence of pre-1872 scarps as well as older late Pleistocene(?) shorelines (Bacon and Burke, 2000). The Lone Pine fault scarps (Figure 1), on the other hand, are located at an elevation of ca. 1160 m, approximately 15 m above the pluvial Owens Lake sill elevation and approximately 40 m higher than an early Holocene transgressive highstand preserved in the northeastern portion of the basin at 1120 m elevation (Orme and Orme, 1993; 2000). Latest Pleistocene highstand lakes may have modified some Lone Pine fault scarps, but they were not modified by Holocene highstand transgressions that modified scarps of the OVFZ.

We have learned that the scarp and shoreline morphologies near Lone Pine are complicated because scarps at elevations below the fluctuating pluvial lake levels experienced one or more episodes of Owens Lake shoreline and associated fluvio-deltaic transgressions. The landscape west of U.S. Highway 395 and near the fault trace appears to have been deeply modified by at least two middle to early Holocene transgressions related to pluvial Owens Lake shorelines and associated fluvio-deltaic erosional processes. The two transgressions eroded pre-existing fault scarps, deposited beach and near-shore lithofacies assemblages (Hla(osi and os), Figure 2), constructed a tufa cemented beach berm (Hla(ys); dashed berm crest) across the fault trace, and produced prominent lacustrine and fluvial tread and riser morphology.

The Owens River meander belt east of U.S. Highway 395 has formed in response to lower base levels during late Holocene and historic lake level fluctuations. Stratigraphic and geomorphic relations at the surface (e.g., Bacon and Burke, 2000) and exposed in trenches reveal that the 3 to 4 m escarpment near Lone Pine also reflects a ca. 1.0-m vertical displacement from the 1872 earthquake. Yet, relations in T5 show that the escarpment is in part a pluvial shoreline, and the deeper stratigraphy records subsurface evidence for only one paleoearthquake. Understanding the Holocene and late Pleistocene lacustrine history is critical to determine accurately the timing and size of paleoearthquakes. The lacustrine and fluvial sequences are datable utilizing identification of several interbedded tephra, 14C dates on charcoal and organic materials, and relative paleosol development, which we are correlating to other sites nearby.

Geomorphology near Pangborn Lane

Recent work by Lee and others (2001) present geomorphic evidence from which they interpret the occurrence of three earthquakes (the 1872 and two paleoearthquakes) at the Pangborn Lane site ca. 1 km south and at the same elevation (~1125 m) of the Quaker paleoseismic site (Figure 2). We do not agree with Lee and others (2001) interpretations on the basis of several lines of evidence, mostly from the wealth of work by previous investigators, as well as the initial results of this ongoing NEHRP project (Burke and others, 2001). The most extensive investigations *along* the entire OVFZ occurred during reconnaissance mapping for the State of California and U.S. Geological Survey seismic hazard assessments as described in Bryant (1988) and in Beanland and Clark (1994), respectively. Neither of these extensive works nor other investigations on the OVFZ near Lone Pine by Slemmons and Cluff (1968), Carver (1970), Hill (1972), Lubetkin and Clark (1988), and Bierman and others (1995) describe a site of lateral offset related to paleoearthquakes on the OVFZ below an elevation of 1140 m.

Figure 2 shows the Pangborn Lane site as well as the Quaker paleoseismic site of this study as summarized in Bacon and Burke (2000). The arrow shows the vicinity where Lee and others (2001) interpret evidence of three laterally-offset and beheaded channels. Lee and others (2001; their Figure 3) show four channels that have incised into the alluvial fan, a present day channel and three older "beheaded" channels on a survey-controlled topographic base map having 20-cm contour intervals. These channels are assumed by Lee and others to be preserved and to record lateral fault slip from Holocene time because they are located below the sill (overflow) elevation of 1145 m, estimated to be last occupied by pluvial Owens Lake between 10-12 ka (Smith and Street-Perrott, 1983; Beanland and Clark, 1994).

We cannot find these channels and small-relief features on the earlier 1:12,000 scale, low-sun-angle aerial photos taken by Slemmons (1968). In the field, the channels shown in Lee and others (2001; their Figure 3) appear to us as shallow rills. A few shallow washes cross the scarp, and, some drainages have been diverted by vehicle ruts, animal trails, and springs along the fault. Some rills appear to source mostly from surface wash and runoff that collects in ruts from vehicles and animal trails. Numerous road scars and animal trails cross the scarp and appear within deflated areas and at the margins of the sand dunes on the upthrown surface (Figure 2). Many old roads here lead northwest and west to an old settlement, a mine, and many prospect pits near the base of the Alabama Hills. Many newer, yet now abandoned roads and scars across the scarp appear to be related to construction of the Los Angeles aqueduct.

Old barbwire and fence posts at the base of a cottonwood tree near springs located 10's of meters north of the Pangborn Lane site indicates to us past ranching activities have occurred nearby. The topo map of Lee and others (2001; their Figure 3) shows a small hill at the top of the fan, which we cannot find on the 1968 photographs. Upon field investigation, we interpret this hill is likely a spoil pile. The scarp morphology is much steeper to the north and south of this site; thus we infer that the gentle slopes here would be favored as a path by range animals and ranch vehicles to travel more easily across the 3-4 m-high scarp.

None of the channels (rills) at the Pangborn Lane site are characteristic of the width, depth, and degree of incision into scarps by channels that are known to be late Pleistocene to Holocene in age (Bierman and others, 1995; Zehfuss and others, 2001). Areas in Owens Valley where surfaces appear well preserved, and free range and ranching activities are restricted, commonly have gullies and channels, that cross the fault, that are one or more meters in depth, as much as 5 times deeper than those shown by Lee and others (2001). The morphology of the most recent channel (C4) shown by Lee and others (2001; their Figure 3) appears as well developed as the other "offset" channels, if not more so, and yet, is interpreted by them to be a post-1872 "present-day" channel. If accurate, the maximum age of channel C4 is 130 yrs old, and its morphology seems to contradict their interpretation that the other channels are Holocene or older in age.

We conclude that the ground surfaces near Pangborn Lane, like other nearby sites, have been disturbed and reworked by animals and humans, likely for thousands of years, yet most recently by road construction and human activities, possibly since 1968, the date of the 1:12,000 photos. It is our interpretation that the channels mapped by Lee and others (2001) are not associated with lateral offsets, but more likely with slope wash and spring discharges that have modified the scarp and are historical to at most latest Holocene in age.

Acknowledgements

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